Proceeding of ICIHCS 2025 Symposium: The Dialogue Between Tradition and Innovation in Language Learning
DOI: 10.54254/2753-7064/2025.HT30752

A Comparative Study of Mineral Pigments in Dunhuang Murals and Italian Frescoes

Guo Ye

Franklin & Marshall College, Lancaster, USA
gye@fandm.edu

Abstract. Mural painting represents one of the oldest art forms in humanity, having an exceptionally significant impact on human aesthetic ideas and technological accomplishments of the East and the West. The results presented in this study suggest that, although Chinese Dunhuang murals and Italian frescoes were situated on separate side of the Eurasian continent, both had much in common regarding their roles as the religious propagators, the arrangement of their compositional forms and material foundation, thus having similar aesthetic perspectives of expressive idealism and realistic depictions. Nonetheless, a certain discrepancy was caused by the inherent differences in natural conditions and cultural priorities, and this led to the fundamental differences in the application of mineral pigments and the expression of color effect in both cultures. It is evident that both sources of pig The conclusion is that such a relationship of similarity in the difference and vice versa is a lively representation of the long-term cultural exchange and learning between the civilizations of the Eurasians through the Silk Road. This research offers a refreshingly material insight into the history of East-Westartistic exchange and thus valuable historical allusions and inspiration to the scientific conservation of ancient murals and thein novative formation of modern murals.

Keywords: Dunhuang Murals, Italian frescoes, mineral pigments, art comparison

1. Introduction

Mural painting, as one of humanity's oldest art forms, carries the aesthetic concepts and technical achievements of Eastern and Western civilizations. This paper takes Chinese Dunhuang murals and Italian frescoes as research subjects, systematically comparing their application of mineral pigments across three dimensions: first, exploring the similarities between Chinese and Western murals in functional purpose, compositional form, and the fundamental use of mineral pigments; second, analyzing the differences in their production techniques, pigment sources, and color expression; finally, examining the influence of Silk Road trade and religious dissemination on the exchange of pigment technology. Through this comparative study, it aims to reveal the commonalities and unique characteristics of Eastern and Western mural art in material science and aesthetic pursuit, providing historical references for ancient mural conservation and modern artistic creation.

DOI: 10.54254/2753-7064/2025.HT30752

2. Chinese and Western murals are similar in features

Despite their belonging to different parts of the Eurasia, Dunhuang murals and Italian frescoes are quite similar in terms of the artistic role, composition structure, and the use of mineral pigments. The similarities represent both general trends in artistic outpouring of humanity and common sense of Eastern and Western civilizations in the form of visual narrative and material science.

Coherence in purpose and functionality is the all-important similarity. Like the Buddhist murals of the Dunhuang Mogao Caves or the religious frescoes of the Italian Renaissance, both served fundamentally the purpose of propagation of their culture and spirit, documenting the figures, events, and scenes of the life they adored [1]. Dunhuang murals communicate Buddhist ideologies and utopian worlds to the believers by using such themes as Jataka stories and sutra paintings; Italian frescoes propagate Christian beliefs with the help of such themes as Biblical stories and lives of saints. They are both significant conveyors of religious art, both to edify and to worship. Eastern and Western murals are often segmented into the upper, middle and lower space in compositional form with the themes in both being; gods, human beings, the sky, the earth etc. [1] creating visual narrative images in cross-cultural visual structure. This arrangement in Dunhuang murals with the Buddhist paradise at the top, earthly scenes in the middle and hell/secular world at the bottom has been used in Italian frescoes, where heaven is the upper section, earth in the middle, and hell in the bottom, as exemplified in The Last Judgment by Michelangelo.

The widespread use of mineral pigments is a significant commonality in material technology, as detailed in Table 1. Both Dunhuang murals and Italian frescoes primarily relied on natural mineral pigments to achieve lasting and vibrant colors. Dunhuang murals "mostly used pigments sourced from what geology terms natural minerals. For example, red cinnabar/vermilion, white gypsum, talc, lapis lazuli, malachite green, mica powder, carbon black, etc., each have their distinct characteristics" [2]. Similarly, Italian frescoes also used mineral-based pigments, such as cinnabar (vermilion) for red, lapis lazuli for blue, and malachite for green. This reliance on mineral pigments stemmed from their excellent stability -- "These natural minerals possess stable properties and strong covering power. Although the variety of colors is not extensive, through combination and blending, they can achieve a myriad of hues. Coupled with the artisans' superb painting skills, this results in… the murals' millennia-long brilliance and vibrant colors" [2].

Both East and West have mastered complex mineral processing and purification in terms of pigment chemistry. The pigments employed in Dunhuang murals were more than 30 types, such as lapis lazuli, litharge, red ocher, malachite green, or piment, realgar, mica powder, antigorite, gypsum, etc. Similarly, making the ultramarine blue of Italian frescoes, which used lapis lazuli, was a very complex and expensive process, sometimes referred to as blue more precious than gold. Both traditions were aware that some mineral pigments were not chemically stable and devised ways of addressing this problem. An example is that in Dunhuang murals minimum pigment readily changes to black on the damp, alkaline layer of ground, and also Italian frescoes suffered the same issues, leading to special preservation methods being developed by artists [2].

Another significant similarity is the development of the color symbolism system. Gold in Dunhuang murals is the symbol of the shine of the Buddhist heaven, the blue lapis lazuli is the symbol of the pure land and the red cinnabar is the symbol of sacred power. In like manner, Italian frescoes gave colors religious connotations, the Saint ; Mary tended to wear a ultramarine, blue robe which symbolized the heavens, the golden halo of Christ and of saints was considered a symbol of divinity and vermilion red was seen as a symbol of sacrifice and love. Such coding of the semantics of color indicates the eastern and western religious art has been constructed with great care as a visual language.

DOI: 10.54254/2753-7064/2025.HT30752

Table 1. Comparison of major mineral pigments in Dunhuang murals and Italian frescoes [3]

Color	Dunhuang Murals Main Pigments	Italian Frescoes Main Pigments	Commonality
Red	Cinnabar, Minium, Red Ocher	Cinnabar, Hematite	Both use Cinnabar
Blue	Lapis Lazuli, Azurite	Lapis Lazuli, Azurite	Lapis Lazuli (precious)
Green	Atacamite, Malachite	Malachite, Green Earth	Copper-based greens
Yellow	Orpiment, Litharge	Ochre, Naples Yellow	Mineral sources
White	Gypsum, Mica, Chalk	Lime White, Chalk	Calcium-based whites

Chinese and Western murals also share commonalities in artistic expression techniques. Dunhuang murals employ "scattered perspective, "where " based on the painter's mood, feelings, and needs, both visible and invisible scenery can be incorporated into the frame [1]. This resonates with the multi-viewpoint compositions used in Italian frescoes to depict religious miracles. Both broke through the limitations of a single viewpoint, creating religious image systems that transcended realistic space. In figure depiction, both Dunhuang murals and Italian frescoes emphasized shaping forms through the combination of line and color. Although specific styles differ, the pursuit of rhythmic form is quite similar.

This cross-regional and cross-cultural similarity partly stems from artistic exchanges along the Silk Road. As a key hub on the Silk Road," several of the over ten main mineral pigments used in Dunhuang cave art… some were transported as finished or semi-finished products from inland China, while ones came from the ancient 'Western Regions' from a far" [4], including lapis lazuli from Afghanistan. Similarly, some pigments used in Italian frescoes might have arrived from the East via trade routes, facilitating indirect exchange in material technology. This exchange was not limited to the material level but also included mutual influence in compositional concepts and symbolic systems, constituting an important chapter in Eurasian art history.

3. Differences in production techniques and representational methods

Despite numerous similarities in function and material basis, Dunhuang murals and Italian frescoes exhibit significant differences in production techniques, technical processes, and artistic expression. These differences stem from the distinct natural environments and architectural traditions of East and West, as well as reflecting their unique aesthetic concepts and cultural values.

The fundamental difference in production technique lies in the basic classification of murals. Italian fresco belongs to the "fresco technique, using newly laid or wet lime plaster. Water is used as the vehicle for dry powder pigments to merge with the plaster, and in the case of plaster, the paint becomes an integral part of the wall" [5]. This technique requires the artist to complete the painting while the plaster is still wet, with the pigment permanently bonding to the wall through a chemical reaction. In contrast, Dunhuang murals are typicaldry frescoes (Fresco secco), "works painted on dried wall surfaces using mineral pigments tempered with glue or egg" [6]. This difference leads to fundamental distinctions in durability, creative freedom, and visual effects, as shown in Table 2.

DOI: 10.54254/2753-7064/2025.HT30752

Table 2. Comparison of dry fresco and wet fresco production techniques

Comparison Dimension	Dunhuang Dry Fresco	Italian Wet Fresco
Base Preparation	Multi-layer mud mixed with plant fibers (wheat straw, hemp fiber, etc.) [7]	Lime and sand mixed wet plaster layer [3]
Painting Timing	Painted after the wall is completely dry	Painted when the wall is partially dry (approx. 7-9 hour window) [3]
Binding Mechanism	Relies on binding agents (animal glue, plant gum) to fix pigments	Pigments chemically react with wet lime, permanently bonding
Modification Possibility	Can be modified and overlaid multiple times	Almost impossible to modify; must be scraped off and redone
Durability	Prone to flaking due to humidity changes	Water-resistant, but the wall substrate is brittle and prone to cracking

Differences in materials and substrate are significant. The substrate of Dunhuang murals typically consists of "coarse sandy mud mixed with bamboo strips, wheat straw [8], or bran, smoothed onto the wall surface. After slightly drying, the surface is leveled. Then, a layer of medium-fine mud and a layer of fine sandy mud are applied, mixed with hemp fiber, paper fiber, or cotton" [6]. This multi-layered structure adapts to the dry climate of northwest China, but "flakes off with alternating cycles of humidity and dryness" [9]. In contrast, the Italian fresco "support made of stone or brick must be dry and without gradients. Before applying the plaster, a mortar composed of slaked lime, coarse river sand, or in some cases pozzolana and water if necessary, is spread to a thickness of 1cm" [5]. Although this substrate is sturdy, "the Italians' insistence on the purest combination of lime and sand resulted in overly brittle walls, vulnerable even to small or medium earthquakes" [9].

Differences in pigment application techniques are also evident. Dunhuang murals use glue-based color techniques, "a method of painting on dried murals using stone powder pigments tempered with glue and egg" [6],allowing artisans to paint in layers and make repeated adjustments. Italian fresco, however, requires the painter to master the giornata technique (daily section), meaning "a rough under layer called arricciois added to the entire area to be painted and allowed to dry for several days… On the day of painting, intonaco, a thinner, smooth fine plaster layer is applied to the amount of wall expected to be finished that day… This area is called giornata" [5]. This technique limits the artist to completing a specific section within a limited time frame, allowing almost no room for error.

Differences in color expression and aesthetic effect stem from different material choices and technical routes. Because Dunhuang murals use the dry method, they could employ a wider variety of pigments, including some unsuitable for the alkaline environment of wet fresco, such as" minium, realgar, red ocher… orpiment, litharge… malachite green," etc. [3], forming a rich and splendid color system. Italian fresco, constrained by the alkaline environment, found that "blue was a particular problem; skies and blue robes were often added a secco (dry), because both azurite and lapis lazuli, the only two blue pigments available at the time, worked poorly in the damp fresco" [5]. This resulted in a more limited color palette for fresco, but it created a strong sense of three-dimensionality through chiaroscuro and spatial perspective.

Differences in artistic style and representational methods reflect the different aesthetic pursuits of East and West. Dunhuang murals embody the "Chinese painting advocacy of 'the spirit of expressive idealism,' advocating the unity of heaven, earth, and man, integrating what the painter sees and thinks into the picture, pursuing an artistic realm where scene and emotion are highly unified" [1].

DOI: 10.54254/2753-7064/2025.HT30752

This style does not emphasize realistic reproduction but focuses on conveying artistic conception and decorative effect. In contrast, Italian fresco embodies the Western "preference for 'the spirit of representational realism,' emphasizing the truthful depiction of objective things" [1], developing precise anatomical representation and spatial perspective, such as Michelangelo "scratching indentations into certain areas of the plaster while still wet to increase the illusion of depth and highlight certain areas" [5].

Differences in conservation and restoration challenges are also note worthy. The main problems facing Dunhuang murals are "the adhesion of pigments to the wall surface, which flakes off with alternating humidity and dryness" [9], as well as color fading due to the aging of binding agents. Italian frescoes, meanwhile, face greater risks of “overly brittle walls" [9] and earthquake damage, as well as issues like the flaking of the calcium carbonate surface layer. These different deterioration patterns require targeted conservation strategies, such as environmental control and binder reinforcement for Dunhuang murals, and structural stabilization and surface treatment for frescoes.

Differences in creative freedom and artistic expression are also quite pronounced. Dunhuang dry fresco allowed artists to "not photograph, not draft, ride a horse around once, have an outline in mind upon return, and execute it in one go" [1], offering greater room for improvisation. Fresco required precise planning; "many artists sketched their compositions with this red pigment called sinopia" [5] or used pouncing transfer methods, making the creative process more rigorous and systematic. This difference allowed Dunhuang murals to retain more flexibility of personal expression, while frescoes exhibit more precise composition and form.

4. Silk road exchange and mutual influence of pigment technology

Although Dunhuang murals and Italian frescoes each have their own characteristics, they were not completely isolated during their long historical development. Through the trade and cultural exchanges of the Silk Road, complex and subtle mutual influences existed between East andWest in areas such as mineral pigment technology and artistic expression techniques. This cross-civilizational dialogue not only enriched their respective artistic expressions but also promoted the development and application of pigment science.

The material exchange of pigment trade is the most direct manifestation of mutual influence between Eastern and Western mural art. As a key hubon the Silk Road, "several of the over ten main mineral pigments used in Dunhuang cave art… some were transported as finished or semi-finished products from inland China, while individual ones came from the ancient 'Western Regions' from afar" [3]. The most precious among these was lapis lazuli from Afghanistan; "Currently, only a few countries like Afghanistan produce lapis lazuli, and no lapis lazu limineral resources have been found in China to date" [3]. This blue pigment, renowned as "more precious than gold," was used not only in Dunhuang murals but later also became an important material for the blue robes of the Virgin Mary in Italian frescoes. Similarly, Chinese-produced cinnabar, malachite green, and other pigments might have also reached the West via the Silk Road, influencing the color system of European painting.

The dissemination and evolution of technical knowledge are equally noteworthy. The "malachite green" pigment technology used in Dunhuang murals shows traces of Sino-foreign exchange: "Records of 'malachitegreen' appear early in documents from the Turpan region of Xinjiang and the Dunhuang Mogao Grottoes library cave… Turpan documents from the Tang Dynasty clearly list malachite green among pigment commodities, indicating that before this, malachite green was already a familiar commodity as a pigment" [3]. This technology likely originated in Persia, later spreading to China via the Silk Road and becoming localized. Similarly, although the Western fresco

DOI: 10.54254/2753-7064/2025.HT30752

technique was not widely adopted in China, some of its concepts, such as lime substrate treatment methods, might have influenced the production of Chinese temple murals. For instance, the Ming Dynasty murals of the Fahai Temple used a more robust "sanhetu" (lime, clay, sand) substrate [7],showing signs of technical fusion.

Color use and composition of a picture represents the exchange of symbolic system in the religious art. The symbolism background of the Dunhuang murals including a golden background and lapis lazuli blue sky have some level of similarity to the employment of golden halo, and the blue robe of the Virgin in Italian frescoes. This resemblance is not necessarily accidental but can be based upon the common borrowing of the visual language of religious art in Eurasia. It is especially interesting that the compositional schemes of certain Buddhist images in Dunhuang murals, like the one termed as the composition frequently subdivided into upper middle and lower layers [1] has been peculiar parallel of the tripartite partitioning of heaven-earth-hell in the Western religious painting. This can be an ordinary visual language created as a result of artistic dialogue in the SilkRoad.

Mutual inspiration in pigment preparation technology is evident in several aspects. Ancient China possessed advanced techniques in mineral pigment processing; "Ancient Chinese alchemy masters already had advanced methods for preparing mica powder during the Han Dynasty. Eastern Han, Sui, and Tang dynasty alchemical texts all contain records methods for making mica powder" [3]. These technologies might have indirectly influenced Western pigment preparation processes via the SilkRoad. Concurrently, Western research on the chemical stability of pigments might have, in turn, influenced the development of Chinese mural conservation techniques, such as the understanding of the darkening mechanism of minimum: "Minium is rarely seen because it is less stable than atacamite" [3] -- knowledge that may partly originate from East-West technical exchange.

5. Research implications

The integrated innovation of modern conservation techniques has become an important trend in contemporary mural research. Facing the respective technical limitations of Dunhuang dry fresco and Italian wet fresco, some artists and researchers have begun experimenting with innovative methods of "combining Chinese and Western mural techniques" [9]. A sone researcher stated: "In the production of the wall base layer, largely adopted traditional Chinese mural techniques, making it sturdier compared to Western fresco. Regarding the wall surface layer, I adopted the Italian fresco method, creating the work while the wall was relatively damp" [9]. This attempt to integrate the advantages of East and West represents a direction for the innovative development of mural technology in the contemporary era.

Transnational collaboration in pigment analysis methods has promoted in-depth mural research. Modern technologies such as “micro-area diffraction analysis" [10], Raman spectroscopy, etc., are widely used in the study of pigments in both Dunhuang murals and Italian frescoes. These cross-border scientific collaborations have revealed more secrets of ancient pigment technology. For example, using micro- diffraction analysis, researchers discovered rare atacamite in Dunhuang murals:" From a 50μm sized pigment sample taken from a polychrome sculpture in the Dunhuang Grottoes, after pretreatment under a stereo microscope, micro-diffraction analysis revealed that atacamite was used as a mural pigment" [3]. Similar techniques are also used to analyze the pigment composition of Italian frescoes, facilitating comparative research on Eastern and Western mural techniques.

There is also the value of East-West exchange in terms of the transmission of technical skills in art education. In modern art schools, the Dunhuang heavy-color technique of the frescoes, the Italian

DOI: 10.54254/2753-7064/2025.HT30752

fresco technique have become the subjects of interest. As an example, the mural project of the China Academy of Art studies the ancient process of dry fresco as well as the modern research of wet fresco process [9]. This education practice assists in the maintenance and creation of the traditions of mural as well as encourages their creative use in the making of modern art.

By carrying out the systematic comparison of both Dunhuang murals and Italian frescoes, one can note that despite the manifested differences in production techniques, material choice, and artistic expression, there also exist great similarities both in the artistic purpose of those works, use of mineral pigments, and their symbolism. It is the relationship of similarity under difference and difference under similarity which in fact is rich expression of cultural exchange and learning between Eurasian civilizations.

Ma materively, both Dunhuang murals and Italian frescoes are very dependent on mineral pigments although the two adopted different technology in their application system. Dunhuang dry fresco is fixed by using binding agents, which allows the expression of rich and varied colors; Italian wet fresco makes use of the chemical reaction of lime to permanently fix the pigments to the wall and this produces different effects in appearance. The two are also different in their emphasis on pigment, with Dunhuang murals enjoying the wide use of a range of local and imported mineral pigments, such as lapis lazuli, cinnabar, at acamite, etc.; and fresco being more restricted and using a more restricted range of pigment on the lime substrate.

6. Conclusion

The given work compared with Chinese Dunhuang mural sand Italian frescoes in a systematic manner allows seeing the rich palette of similarities and differences between the mural art of the East and the West in the terms of material science and in aesthetic pursuit. The essence of the results is in the fact that, First, both have transcendent similarities in human art across regions-- performing the essential task of religious dissemination, using stratified composition patterns of narrative, using natural mineral pigments as indispensable substances. This indicates the common sense of various civilizations towards visual narrative, material permanence. Secondly, due to natural environment, technical customs, and philosophical ideas, they have invented the crucial distinction between the use of dry and wet fresco production techniques, which has then imposed considerable variation in terms of expressiveness of color, aesthetic beauty (Eastern expressive idealism vs. Western representational realism), and their permanence.

More significantly, the Silk Road, as the major conduit of ancient East-Westcultural interaction, had not only provided the trade in valuable pigments, such as lapis lazuli, but also indirectly led to the interaction and infusion of pigment preparation cultural systems, colour symbolism systems and art forms, representing one of the significant consequences in Eurasian art history. This research shows that, Dunhuang murals and Italian frescoes are crystallization of art because of simultaneous growth and reciprocal influence.

This comparative analysis not only makes the nature of the Eastern and the Western art more comprehensible but also has a dual implication on the further epoch of our times that alternately, on the practical side, the scientific conservation of these two types of mural offers a certain strict theoretical foundation, and on the creative side of the modern mural production provides new possibilities of material components fusion and technical development. At the Ona cultural level, it is a potent confirmation of the timeless truth that global civilisation can get more diverse with an exchange and enrich with mutual learning, which can be used as a valuable paradigm to study the history of art globally and to preserve the cultural heritage in the country.

DOI: 10.54254/2753-7064/2025.HT30752

References

[1] Wang, Q. (2008) A Comparative Study of Chinese and Western Mural Art. Higher Education Press, Beijing.
[2] Chen, S. and Zhang, Y. (2015) Study on the Stability and Aging Mechanism of Mineral Pigments in Dunhuang Murals. Sciences of Conservation and Archaeology, 27(3), 45-52.
[3] Mora, P., Mora, L. and Philippot, P. (1984) Conservation of Wall Paintings. Butterworths.
[4] Li, C. (2019) A Study on the Application of the Integration of Fresco and Secco Techniques in Contemporary Mural Creation (Master's Thesis). China Academy of Art.
[5] Wang, J., Su, B. and Yu, Z. (2017) New Discoveries from Micro-Diffraction Analysis of Pigments from the Mogao Grottoes, Dunhuang. Dunhuang Research, (5), 121-128.
[6] Duan, W. (2011) Ten Lectures on Dunhuang Art. Shanghai Ancient Books Publishing House, Shanghai.
[7] Jin, W. (1998) Ancient Chinese Temple Murals. Cultural Relics Press, Beijing.
[8] Wang, J. (2009) A Study on the History and Sources of Mineral Pigments Used in the Art of Dunhuang Grottoes. Chinese Historical Relics, (3), 78-85.
[9] Getty Conservation Institute. (2003) Walls of Heritage, Walls of Tomorrow: Conservation of Wall Paintings. Getty Publications.
[10] Bikiaris, D., Daniilia, S., Sotiropoulou, S., Katsimbiri, O., Pavlidou, E., Moutsatsou, A.P. and Chryssoulakis, Y. (2000) Ochre-Differentiation through Micro-Raman and Micro-FTIR Spectroscopies: Application on Wall Paintings at Meteora and Mount Athos, Greece. Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy, 56(1), 3-18.